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MATERIALS INFORMATION

A SUMMARY OF AGGREGATE DURABILITY INVESTIGATIONS OF A. G. COOK QUARRY WAUBAUSHENE, ONTARIO.

BY

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1. INTRODUCTION

A. G. Cook Ltd. Quarry (Mineral Aggregate Inventory No. P22-035) is located in Tay Township, Lot 9 conc. 14, 4.5 km NE of Waubaushene.

At present, the quarry operation is carried out on two lifts and it produces aggregates for asphalt, (HL3, 5, 6) concrete and granular uses.

The rock extracted is from the Middle Ordovician, Gull River Formation (Lower Member) with the floor of the quarry in the shaley and silty Shadow Lake Formation.

Because of alkali carbonate reactivity problems with rocks from the Gull River Formation and the shaley nature of parts of the quarry, detailed investigations and testing have been carried out.

In this report, the results of the testing are compiled and tabulated with appropriate recommendations for the use of the aggregates from this source.

2. SUMMARY OF INVESTIGATIONS

1 - An investigation by G. Woda in 1970 consisted of:

a - A description of the quarry face and drill core - Figure 1.

b - Chemical analysis, insoluble residue and rock cylinder expansion tests (ASTM C586) - Tables 1 and 2.

This work was carried out on face samples from the first and second lifts and drill core samples of the Shadow Lake Formation.

2 - Concrete prism expansion testing (CSA A23.2-14A) carried out in 1971 on aggregate produced from first lift - see Appendix 1.

3 - An investigation of "a particle cracking phenomenon" affecting the performance of the aggregates by G. Woda and K. Ingham 1972 - see Appendix 2.

4 - Laboratory test results on routine samples from 1967 to 1979 - Table 3.

5 - Alkali-carbonate reaction test (CSA A23.2-14A) carried out in in 1979 on the aggregate produced from top 3.3 m (11 feet) of the second lift. See Figures 2 and 3.

6 - Aggregate durability test done on the face samples (laboratory crushed) taken from a 1.5 m (5 foot) section of the second lift - see Table 4.

3. DISCUSSION

3.1 Alkali-Carbonate Reaction

The results of the rock cylinder expansion tests, ASTM C586, (Table 1) show that there are two zones of alkali-reactive rock. These are found between the top of the quarry and 3 feet below the top (Samples 21, 24, 25 and 26). The second zone is found between 19 and 22 feet below the top (Samples 5, 6 and 7). Nearly all the other samples showed shrinkage rather than expansion following storage in 1N sodium hydroide solution. This is normal for non-reactive carbonates.

The results of the concrete prism expansion test (appendix 1) conducted on the first lift at the same time as the rock cylinder expansion tests showed that the aggregate, when tested in a cement of 1% alkali content (Na_2O equivalent), did not expand excessively. There are two possibilities:

Either, the rock was quarried in such a way that the reactive material from the top three feet was not included in the concrete aggregate. Some undulation in bedrock topography might be a reason.

or the reactive material was diluted sufficiently by the underlying non-reactive rock so that negligible expansion occurred.

It is worth noting that the prisms prepared with 3 percent alkali expanded significantly, indicating that there were some reactive constituents present. These were apparently not sufficiently abundant to produce excessive expansion at normal alkali contents.

Unfortunately, since 1971, the maximum alkali content of normal Ontario cements has increased from about 1 percent to about 1.25 percent. A re-test of the first lift should be conducted.

In the case of the lower reactive zone from 19 to 22 feet below the top, the concrete prism expansion test (Figure 2) supports the rock cylinder expansion results. That is, the rock is alkali-carbonate reactive. Figure 5 shows the occurrence of dark reaction rims on some particles of coarse aggregate, confirming the existence of a reaction between cement and aggregate. Figure 6 shows photomicrographs of the affected aggregate particles. Note the appearance of the classic "reactive" texture.

3.2 Cracking of Particles in Asphalt

The results of investigations by G. Woda and K. Ingham were never brought to a satisfactory conclusion (Appendix 2).

Later testing by G. Woda and observations by C. Rogers showed that some particles were susceptible to cracking caused by a thermal expansion /contraction phenomenon. Two pieces of very fine grained, lithographic limestone were cut and polished. They were then exposed in the window to sunlight for 6 months. At the end of this time, cracking was observed as shown in Figure 4.

Observations at the MTC owned Medonte quarry of similar rock also showed this phenomenon in situ. This rock when exposed to natural conditions develops a system of random cracks on the surface. This is accentuated by subsequent preferential dissolution of the material in the cracks by acid rainfall. The depth of penetration of these cracks into the rock is about 1 cm.

Observations of road surfaces containing these cream or white coloured lithographic limestones also show this system of random cracks. Parts of the parking lot at Downsview have excellent examples (Figure 8). The cracking occurs at an early age. Freezing and thawing is not necessary to induce the cracking. Following the cracking, further deterioration does not take place provided that the aggregate particle is firmly bonded to asphalt.

Observations of concrete containing these lithographic limestones shows that when the sample is taken from the interior of the structure the particles are not cracked. When the lithographic limestone is at, or near the surface cracking does occur (Figure 7).

Clearly, this unusual rock should be studied in more detail. It is hoped to include a sample in a research program to study the thermal expansion and contraction properties of some Ontario rocks in 1983.

4. RECOMMENDATIONS

On the basis of the testing carried out to date it is recommended that:

1. The aggregate produced from the top 3.7 m (upper or first lift) of the quarry is acceptable for use in asphalt.

2. The aggregate produced from the top 3.7 m (upper or first lift) of the quarry is currently acceptable for use in portland cement concrete when the alkali content of the cement is 1% Na_2O equivalent or less. It is recommended that this aggregate be re-tested to deterimine its alkali carbonate reactivity at 1.25% Na_2O equivalent alkalies.

3. The aggregate produced from the top 3.3 m (11 feet) of the second lift is acceptable for use in asphalt (but is not acceptable for concrete due to alkali carbonate reactivity) providing that the top layer (approx. 30 cm (1 foot), consisting of argillaceous dolostone, commonly known as "a green marker" is stripped before blasting.

4. The aggregate produced from section 3.3 m to 4.9 m (11 to 16 feet) of the second lift is only acceptable for granular uses.

5. The aggregate produced from below 4.9 m (16 feet) of the second lift is not accepted for any MTC aggregate uses.

It is further recommended that a survey of concrete elements and structures built since 1971 using this aggregate be conducted.

TABLE 1
RESULTS OF TESTING 26 HAND SPECIMENS
ROCK CYLINDER EXPANSION TEST

SAMPLE NO.	CHEMICAL ANALYSIS				EXPANSION IN PERCENT		
	CaO%	MgO%	CaO:MgO	INSOLUBLE RESIDUE %	4 WEEKS	12 WEEKS	26 WEEKS
26 TOP	47.2	4.26	11.1	4.8	*0.138	0.198	0.206
25	46.0	3.16	14.6	6.5	*1.470[1]		
24	88.7	11.0	3.5	5.3	*0.271	0.320	0.312
23	52.9	1.64	32.3	2.5	-0.008	0.000	-0.012
22	53.8	0.68	>50	2.3	-0.053	-0.061	-0.074
21	51.3	1.26	40.7	4.9	*0.124	0.166	0.190
20	52.6	Trace	>50	3.5	-0.009	-0.005	-0.013
19	52.9	Trace	>50	3.7	0.040	0.048	0.025
18	53.5	Trace	>50	2.2	-0.054	-0.066	-0.078
17	53.2	Trace	>50	3.4	-0.057	-0.074	-0.074
16	53.1	0.72	>50	2.5	-0.066	-0.082	-0.095
15	51.2	1.05	48.8	5.3	-0.038	-0.042	-0.038
14	50.9	0.88	>50	5.7	-0.038	-0.054	-0.053
13	50.0	1.07	46.7	7.2	-0.012	-0.037	-0.045
12	29.95	7.78	3.8	26.3	0.040	0.068	0.108
11	32.95	13.75	2.4	8.9	-0.004	0.009	0.009
10	34.5	15.65	2.2	8.3	-0.017	-0.032	-0.048
9	36.1	13.75	2.6	4.7	-0.024	-0.040	-0.043
8	48.6	4.16	11.7	4.7	0.037	0.045	0.041
7	44.0	6.05	7.3	7.1	*0.399	0.580	0.633
6	45.0	5.20	8.7	7.6	*0.354	0.406	0.439
5	37.2	11.35	3.3	6.2	*0.862	1.018	1.038
4	31.3	15.95	2.0	8.2	-0.061	-0.076	-0.064
3	51.8	1.72	30.1	4.0	-0.054	-0.066	-0.075
2	51.5	2.64	19.5	2.3	-0.024	-0.028	-0.020
1 BOTTOM	31.8	14.7	2.2	11.4	-0.024	0.050	0.144

NOTE 1. Cylinders broke @ 2 weeks.
* Greater than 0.1% expansion @ 4 weeks indicates a possible alkali-carbonate reactive rock.

TABLE 2
RESULTS OF TESTING
8 SAMPLES OF DRILL CORE

SAMPLE NO.	CHEMICAL ANALYSIS			
	CaO%	MgO%	CaO:MgO	INSOLUBLE RESIDUE %
-1	30.2	12.8	2.3	11.4
-2	18.2	7.45	2.4	46.2
-3	19.4	10.3	1.9	35.9
-4	24.5	12.7	1.9	21.7
-5	29.7	15.1	2.0	11.6
-6	19.4	9.12	2.1	34.0
-7	19.1	9.76	2.0	36.7
-8	2.8	Trace	-	89.9

TABLE 3
LABORATORY TEST RESULTS
1967 - 1979

SAMPLE NUMBER	MATERIAL	PN GRANULAR	PN HL & CONC	Mg SO_4 % Loss	LA % Loss	Abs %	RELATIVE DENSITY	
67-B-20354		100.0	111.6	-	-	-	-	25' face
68-B-20009	GBC		119.7	13.2	23.2	1.50	2.65	
68-B-20010	GBC	102.0	111.0	11.4	20.1	1.30	2.68	
68-B-20011	2" cr. run	115.4	126.0	16.2	23.8	1.20	2.67	
68-B-20012	"	109.5	130.7	14.0	-	1.30	2.67	
68-B-20019	HL3	100.0	107.2	8.7	20.7	1.60	2.64	
68-B-20043	2"	100.0	111.6	9.4	20.2	1.40	2.68	
68-B-20044	HL6	100.0	110.4	11.2	20.4	1.30	2.66	Material produced from total face
68-B-20045	HL6	116.9	125.9	9.0	20.6	1.07	2.69	
68-B-20046	Rock Fragment	-	166.0	67.1	-	-	-	Rock fragments from silty limestone layer
68-B-20047	HL3	108.1	117.0	7.7	21.2	1.33	2.67	
68-B-20048	HL3	102.6	110.0	9.0	20.4	1.23	2.69	Material produced from total 25' face
68-B-20056	HL3	109.5	126.5	12.7	21.8	1.17	2.67	
68-B-20057	HL3	-	138.5	14.0	21.2	1.40	2.67	
68-B-20124	HL6	103.0	116.0	15.0	21.1	0.96	2.67	
68-B-20125	HL6	104.4	117.4	15.9	20.9	-	-	
68-B-20140	HL3	103.8	117.4	5.0	21.8	0.96	2.66	
68-B-20141	HL3	101.8	106.3	6.3	22.1	1.00	2.68	
68-B-20142	HL5	109.7	125.8	4.7	21.6	0.76	2.68	Material produced from Upper 10' level
68-B-20143	HL5	110.0	118.2	6.0	21.4	0.90	2.67	of the quarry
68-B-20144	HL6	110.9	125.9	7.9	21.9	0.83	2.68	
68-B-20145	HL6	101.9	128.1	7.5	22.2	0.86	2.67	
69-B-20187	HL6	110.6	114.0	14.1	21.9	1.00	2.666	
69-B-20188	HL3	109.2	119.8	3.3	21.6	1.17	2.656	
70-B-20132	HL3	104.2	118.8	10.3	23.9	1.03	2.659	
70-B-20133	HL6	113.0	114.6	9.3	23.1	0.93	2.663	
70-B-20141	HL6	112.4	113.7	12.2	22.8	1.00	2.661	
70-B-20142	HL3	109.2	113.3	10.2	-	-	-	
71-B-20127	HL6	107.6	112.3	9.4	22.6	1.17	2.649	
71-B-20128	HL3	107.1	115.1	8.0	20.7	1.03	2.656	
72-B-20141	HL3	122.2	132.8	16.0	23.0	1.41	2.630	
72-B-20209	HL5	101.0	108.4	11.1	24.5	1.30	2.638	
72-B-20210	HL3	109.5	116.3	16.3	25.1	1.40	2.630	

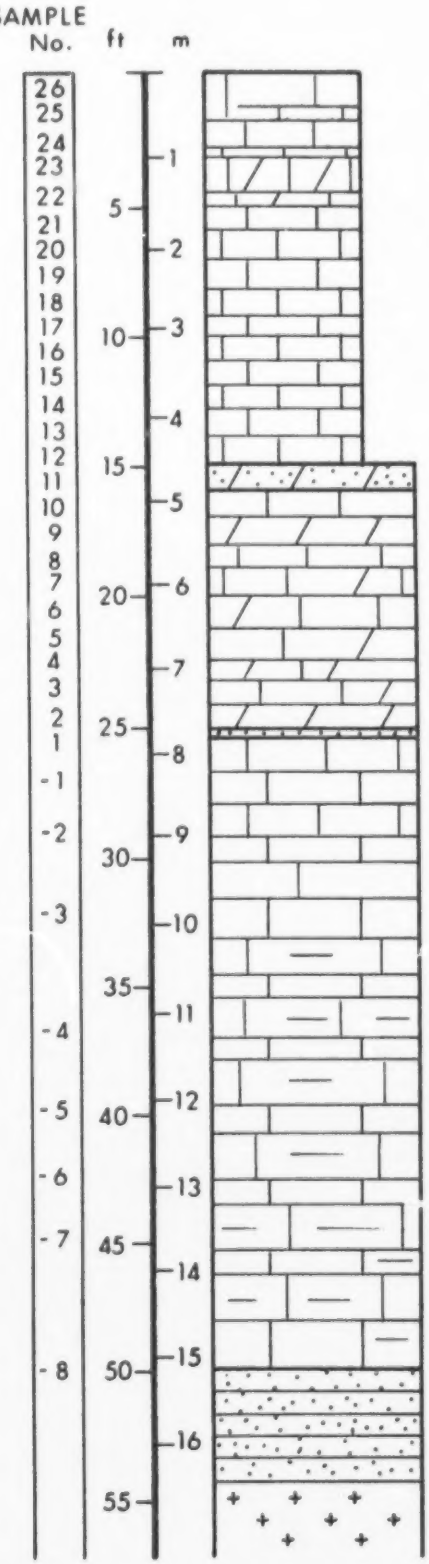
TABLE 3 - CONTINUED
LABORATORY TEST RESULTS
1967 - 1979

SAMPLE NUMBER	MATERIAL	PN GRANULAR	PN HL & CONC	Mg SO_4 % Loss	LA % Loss	Abs %	RELATIVE DENSITY	
73-B-20071	HL3	104.8	125.0	18.7	23.0	1.07	2.657	
73-B-20072	HL5	101.2	112.0	20.3	-	0.83	2.662	
73-B-20219	HL3	106.2	117.7	1.9	-	1.26	2.696	
73-B-20220	?	103.2	108.6	12.7	-	1.00	2.661	
73-B-20221	?	107.5	117.3	14.4	22.8	0.96	2.660	
74-B-20059	HL3	107.4	114.4	11.7	21.4	1.03	2.659	
74-B-20065	HL3	105.3	115.0	11.7	24.1	1.160	2.651	
74-B-20066	HL5	102.8	107.2	15.6	-	1.06	2.653	
74-B-20067	HL6	101.5	111.9	17.8	22.5	0.96	2.661	
75-B-20120	HL5	108.7	117.8	19.4	25.5	1.10	2.664	
75-B-20121	HL3	121.1	129.2	27.0	27.1	1.10	2.652	
75-B-20284	HL3	116.3	124.8	19.7	23.6	1.27	2.643	
75-B-20285	HL5	107.3	108.9	7.4	-	0.83	2.668	
75-B-20286	3/4 st.	106.4	123.4	12.1	-	0.96	2.659	
75-B-20373	A mat.	102.8	118.9	24.7	25.7	1.84	2.649	Lower lift
75-B-20377	HL6	100.0	110.0	25.6	26.3	1.75	2.661	Lower lift
75-B-20378	HL6	102.6	110.8	26.1	25.7	1.88	2.645	Lower lift
75-B-20570	HL5	103.1	105.7	11.4	24.0	1.00	2.659	
75-B-20571	HL3	108.5	112.2	15.3	25.3	1.370	2.626	
76-B-20234	HL3	104.9	108.1	11.3	24.8	1.35	2.642	
76-B-20235	HL4	101.7	106.0	9.0	24.5	1.07	2.666	
76-B-20256	HL3	107.3	110.7	9.0	24.9	1.32	2.642	
76-B-20257	HL4	103.1	107.0	12.7	24.2	1.37	2.649	
77-B-20351	HL3	105.7	111.4	3.7	27.6	1.14	2.651	
77-B-20352	HL4	104.4	111.3	9.2	22.2	1.23	2.643	
78-B-20290	HL3	101.0	104.6	9.6	21.9	1.00	2.665	
78-B-20291	HL5	106.5	106.9	4.8	24.3	0.97	2.668	
79-B-20131	HL4	102.2	107.7	14.8	23.2	1.30	2.684	
79-B-20132	HL6	107.0	107.0	6.5	21.3	1.27	2.686	
79-B-20133	HL6	100.0	103.0	6.6	20.7	1.17	2.687	
79-B-20361	HL3	104.9	111.9	10.4	22.1	0.97	2.662	
79-B-20362	HL4	102.2	107.6	4.2	20.5	1.04	2.666	
79-B-20363	HL6	104.6	108.1	10.8	23.2	1.04	2.666	

TABLE 4: A. G. COOK LTD. QUARRY
second lift - east face

TOP SEC. LEVEL	HEIGHT cm	HEIGHT %	SAMPLE NO.	PN	Mg SO_4 % Loss	ABSN %	SAMPLE NO.	Mg SO_4 % Loss	ABSN %
	345.4	69.4	79-B-20131	107.7	14.8	1.3	Processed material samples		
			79-B-20132	107.0	6.5	1.27			
			79-B-20133	103.0	6.6	1.17			
	AVERAGE			105.9	9.1	1.25			
1	25.4	5.1	79-B-20275	271.4	72.4	3.79	79-B-20233	45.1	3.25
2	27.9	5.6	79-B-20276	264.9	24.1	3.37	79-B-20234	22.3	3.45
3	15.2	3.1	79-B-20277	130.3	13.2	2.62	79-B-20235	19.2	2.58
4	25.4	5.1	79-B-20278	102.8	6.1	1.27	79-B-20236	8.1	1.1
5	58.4	11.7	79-B-20279	106.1	5.6	1.47	79-B-20237	8.6	1.37
6	12.7		Not tested - bed excluded				79-B-20238	89.7	4.92
average - beds 1-5				164.6	21.0	2.28		18.2	2.14
average - 2nd Lift				123.8	12.7	1.57		11.9	1.52

A.G. COOK LTD. QUARRY - COLUMNAR SECTION



LIMEST - brown grey, lithographic thin bedded

DOLOMITIC LIMEST - grey, lithographic, thin to med. bedded, fossiliferous, glauconitic

LIMEST - brown-grey, lithographic, med. bedded, mottled, fossiliferous, calcite crystal

LIMEST - grey-brown with green spots, lithographic, shale seams

DOLOMITIC - limest, greenish grey, mottled, sandy, silty

DOLOMITIC - limest, greenish grey & brown-grey, med. bedded, fossiliferous, irregular shale seams

DOLOMITIC - limest, sandy with glauconite & pyrite

DOLOSTONE - very argillaceous, light greenish grey, occasional silty beds, occasionally porous, very argillaceous dolosiltite (like a shale)

ARKOSIC SANDSTONE - light greenish-grey, poorly sorted, porous, calcitic cement

GNEISS

FIGURE 1

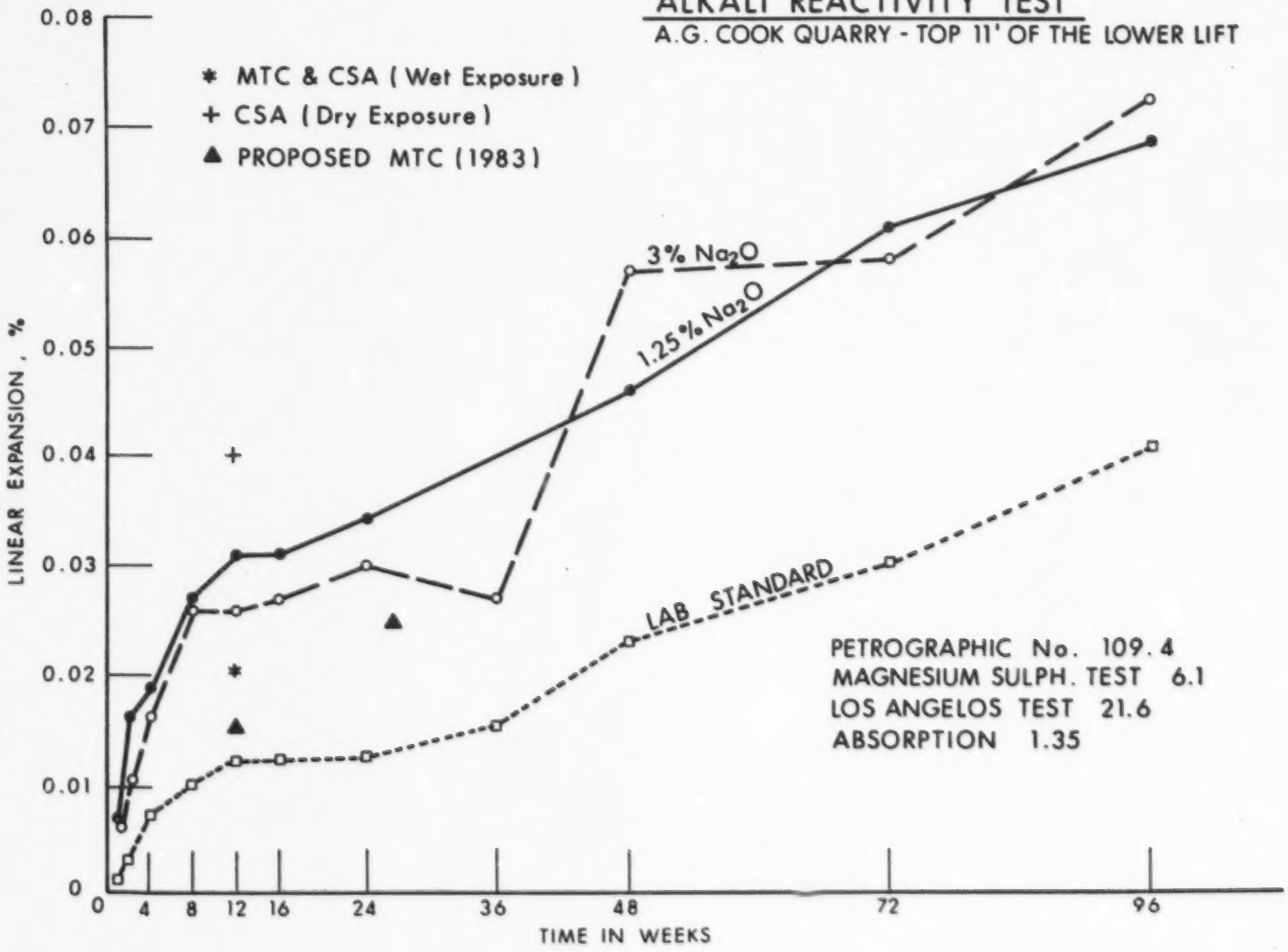

ALKALI REACTIVITY TEST
A.G. COOK QUARRY - TOP 11' OF THE LOWER LIFT
* MTC & CSA (Wet Exposure)
+ CSA (Dry Exposure)
▲ PROPOSED MTC (1983)
3% Na2O
1.25% Na2O
LAB STANDARD
PETROGRAPHIC No. 109.4
MAGNESIUM SULPH. TEST 6.1
LOS ANGELOS TEST 21.6
ABSORPTION 1.35
LINEAR EXPANSION, %
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0 4 8 12 16 24 36 48 72 96
TIME IN WEEKS

FIGURE 2

A.G. COOK LTD. QUARRY

SECOND LIFT - NORTH FACE

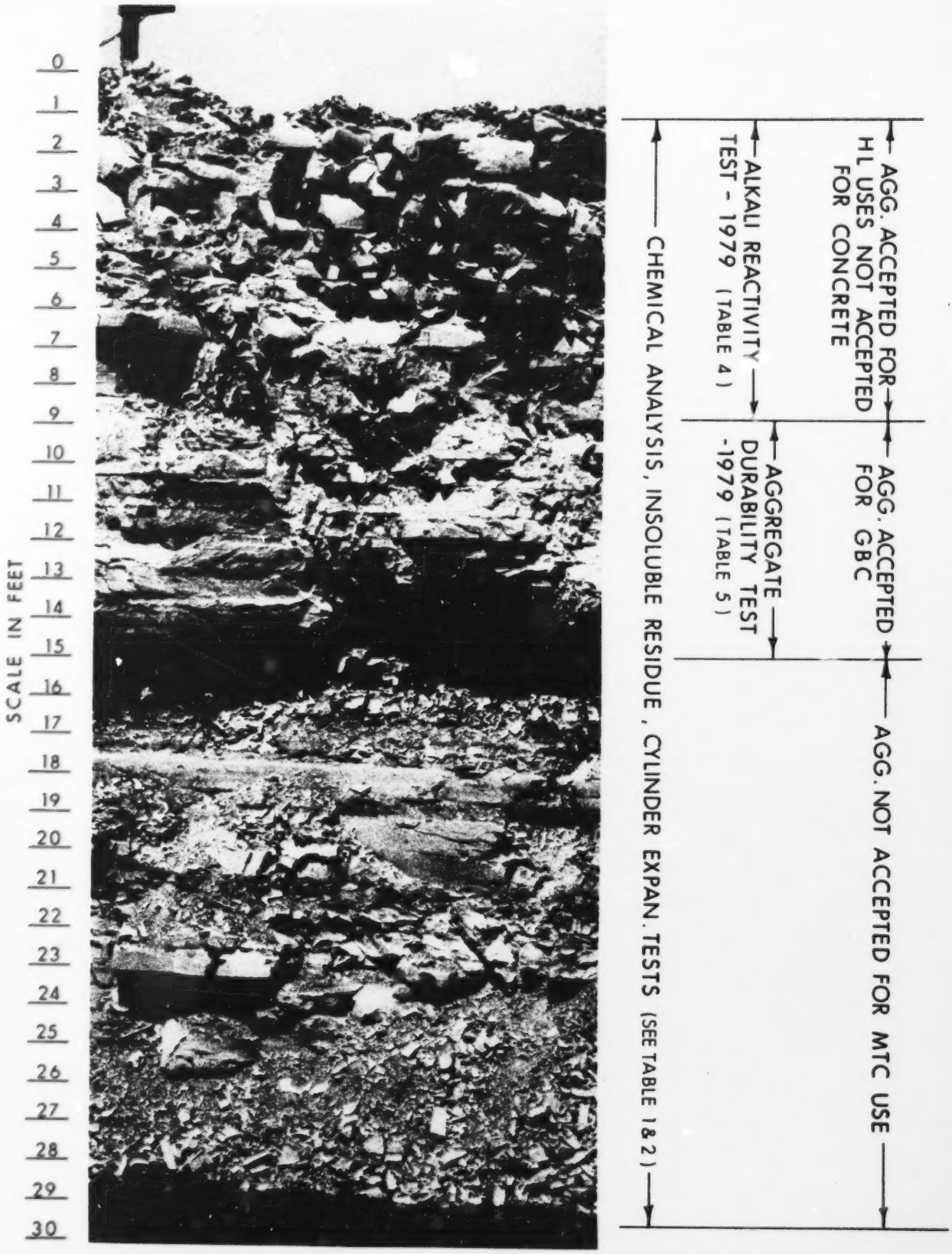


FIGURE 3

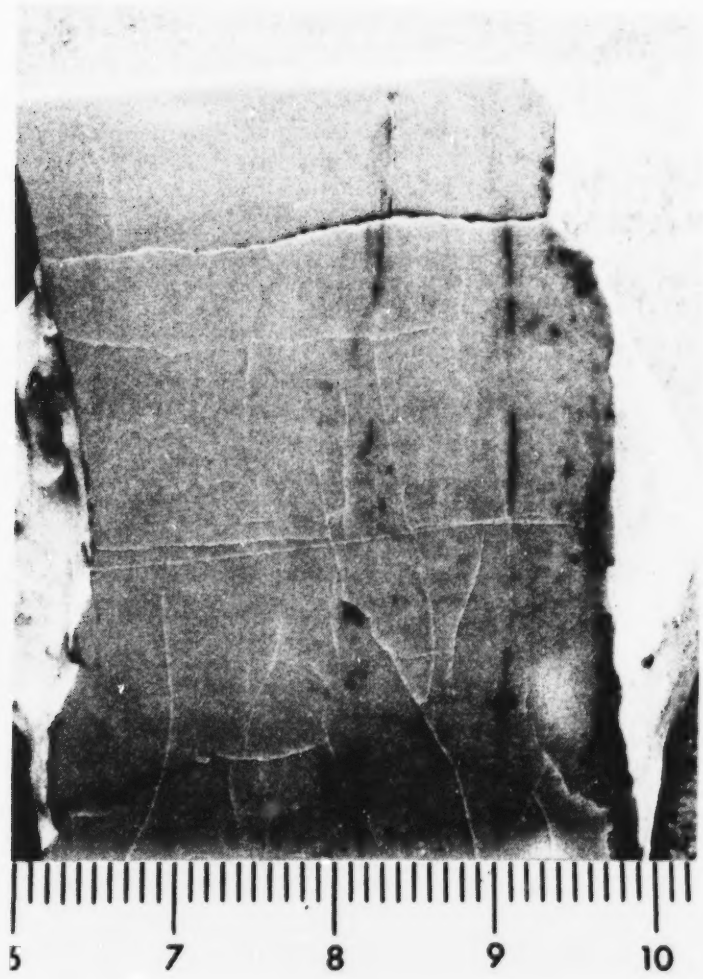


FIGURE 4: Appearance of polished surface of lithographic limestone after 6 months exposure to sunlight. Note cracks that developed during this exposure.

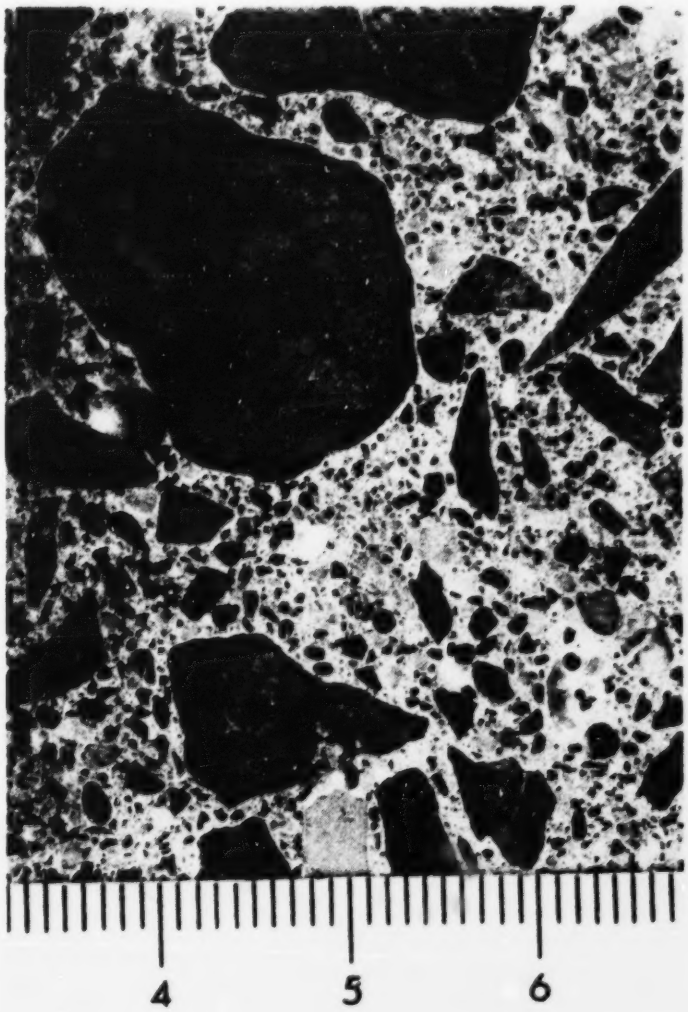


FIGURE 5: Polished surface of concrete tested in 1979 (See Figure 2). Coarse aggregate from top 11' of lower lift. Note dark reaction rims on some particles. 3% Na_2O equivalent alkalies.

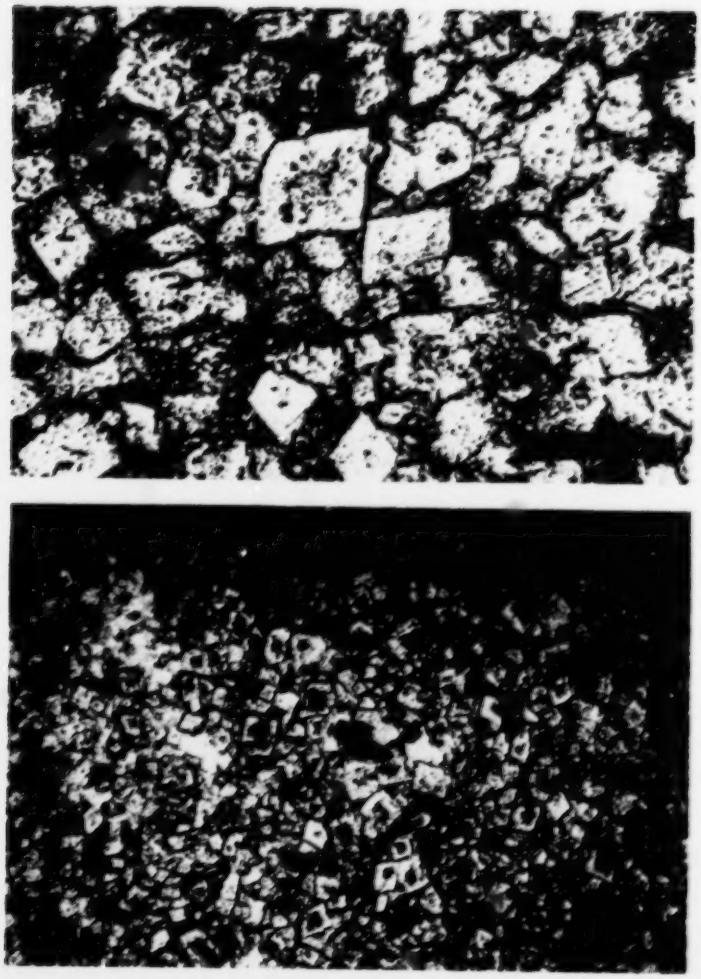


FIGURE 6: Photomicrographs of thin sections of coarse aggregate particles showing reaction rims in Figure 5. Length of scale bar = 0.1 mm. Note euhedral crystals of clear dolomite in a cloudy micritic matrix.

FIGURE 7: Cracked particle of lithographic limestone in deteriorated portland cement concrete. Age about 30 years.

FIGURE 8: Cracked particle of lithographic limestone in 20 year old pavement surface. Despite cracking, particle has remained in the surface of this lightly trafficked pavement.

APPENDIX 1

DEPARTMENT OF HIGHWAYS ONTARIO

MEMORANDUM

TO: Mr. W. R. Bennett,
Principal Materials Engineer.

FROM: Testing Engineers.

ATTENTION:

DATE: October 18, 1971.

OUR FILE REF.

IN REPLY TO

SUBJECT: Alkali-Aggregate Reaction, Allan Cook Quarry, Waubashene (Lab. #71-B-60052)

In May 1971 Mr. B. K. Glassford submitted a sample (71-WC-1020) of coarse aggregate from this quarry for alkali-aggregate reaction test.

The material has been tested in accordance with "DTC Test Method for Volume Change of Cement-Aggregate Combinations (Coarse Aggregate)." The Test results are as follows:

Age	Length Change %					
	Test Aggregate			Control Aggregate (Nelson Quarry)		
	Alkali Content %					
	L. A.	1.0	3.0	L.A.	1.0	3.0
1	0	0	0	0	0	0
7	+.0023	+.0008	+.0048	+.0008	+.0008	+.0045
28	+.0043	+.0076	+.0147	+.0028	+.0066	+.0093
84	+.0051	+.0109	+.0318	+.0075	+.0068	+.0154
168	+.006	+.014	+.045	-	-	-

The concrete prisms with 1% alkali content by weight of cement had an expansion of .0109% at 84 days. The Department specification allows an expansion of max. .02% at this age.

The coarse aggregate does not cause excessive expansion in concrete and, from this point of view, is acceptable for use in Portland Cement Concrete.

B. Chojnacki

BC:mvh

B. Chojnacki,
Concrete Development Engineer.

cc: T. Kovich
J. Roy
Z. Katona

APPENDIX 2

DEPARTMENT OF TRANSPORTATION AND COMMUNICATIONS

MEMORANDUM

TO: Mr.A.Rutka,
Materials and Testing Engineer.

FROM: G.Woda,
Petrographer.

ATTENTION:

DATE: August 14, 1972.

OUR FILE REF.

IN REPLY TO

SUBJECT:

Pavement Investigation of Highway #12

Midland -By-pass and Highway #35: Norland

Coarse Aggregate from A.Cook Quarry

A few weeks ago I investigated Highway #12 (Contract 70 - 206) and found that the pavement in this area had a relatively high amount of fractured aggregate particles: at least one half of the exposed particles were affected to some extent by the shattering.

There has, however, been some loss of aggregate particles due to weathering or traffic action causing pop-outs.

At first it was assumed that such shattering was initially due to the compaction by a heavy roller on the cold asphalt since the asphalt was laid late in the fall of 1971 and the pavement laid last spring is in good condition with none of the particles fractured.

Further to our discussion of this matter; I obtained more information on August 9, 1972 when B.Glassford, Z.Koniuszy and I investigated Highway #35 - just north and south of Norland, which was built in 1970 with the same aggregate.

In general, the highway appears not too bad with some pop-outs due to silty greenish dolomite, but at least half of other aggregate particles are fractured the same way as in Highway #12.

Studying this phenomenon on the spot, revealed that the traffic initially is not resposible for the shattering of the particles,- since such shattering appears evenly over the whole width of the pavement. It was noted that the affected particles are usually relatively dense and sound, and with a low absorption and insoluble residue.

It is obvious that we face some kind of unusual action, which up to now has not been considered. Presumably, some dense carbonates have a kind of internal tension that makes them susceptible to low temperatures or other factors. This phenomenon will be studied in the near future.

G.Woda,
Petrographer.

GW:mb
c.c.

DEPARTMENT OF TRANSPORTATION AND COMMUNICATIONS

MEMORANDUM

TO: Mr. W. R. Bennett,
Principal Materials Engineer.

FROM: K. W. Ingham

ATTENTION:

DATE: October 26, 1972

OUR FILE REF.

IN REPLY TO

SUBJECT: The Cracking and Disintegration of Limestone from A. Cooke & Sons Co. Ltd. Quarry at Waubaushene

We have now completed a brief survey not only of the lithology, properties and performance of the Cooke material but other limestones and dolomites commonly used in asphalt paving. All carbonates exhibit a certain amount of this type of cracking as do some of the other rock types--notably granite. In general, the range of cracked particles runs up to about 20 percent which is certainly a different order of magnitude from Uhthoff aggregate at approximately 50 percent and the Cooke material closer to 75 percent. The only quarried carbonate to show very little cracking is the porous type of dolomite from the Nelson, Milton, Acton groups of quarries. These are the aggregates with the highest L.A. losses (perhaps cracking is inversely proportioned to the L.A. loss!).

Generally it does seem that it is the very fine grained dense carbonates that are most prone to behave in this manner. Beds of this type in the Cayuga Dunville-Fort Erie group of quarries show this same phenomenon, whereas the softer beds do not. The same is roughly true of the Black River group of rocks in the Kingston-Belleville area and the Detroit River group in the Woodstock area. So far at least then the problem appears to be confined to the Midland-Uhthoff area, although geologically similar rocks do occur much further to the east.

In the search for an answer to the problem, the high incidence of fracturing in the Midland-Uhthoff type of limestone suggests that it is a fundamental property of this rock, for if it were not presumably the phenomenon would be far more widespread. We have examined thin sections of the various strata in the Cooke quarry without detecting any micro-cracks, as we have in the past with sections from Uhthoff. The possibilities of any weakness being induced by blasting is most unlikely as again it would be a universal feature of quarried aggregate and it does not seem possible that it could survive the crushing operation. The primary impact breaker at

Cooke's quarry would probably eliminate any cracked material present in the feed. Whether or not micro-cracks can be introduced at the secondary crushing stage has not as yet been evaluated however, but the sized aggregate taken from stockpile does not reveal any incipient cracking under megascopic examination. The secondary crushing is a cone crusher process as it is at Uhthoff.

Pavement evaluation of this type of performance is somewhat unusual as we are normally trying to guess at the nature of material that has already weathered out and here we have the phenomenon well preserved for examination. The significance of this, and it must be emphasized, is that we have pavements 15 or more years old displaying this relatively high degree of cracking but with very little surface loss of aggregate. There are many examples such as the H.L.3 pavement on Highway 2 between Whitby and Pickering laid in 1956, Metro roads and numerous parking lots throughout the City all showing more or less the same amount of cracking and similar performance.

The face at Cooke's quarry corresponds to the lower level at Uhthoff first used in H.L. paving on Highway 93 north of Barrie in 1960. Here again we have the familiar cracking but adequate performance in terms of surface loss of aggregate. As mentioned previously, in the pavements examined, Cooke's aggregate displays a higher order of loss again than the Uhthoff stone although both are essentially from the same geological horizon, in fact areas of the H.L.3 pavement, Contract 71-142 on highway at Midland, show as much as 90 percent cracking of the coarse aggregate after approximately a year of useful life. A similar situation exists in the H.L.5 pavement surface on Highway 35 at Norland. The difference between this and the Uhthoff situation is more apparent than real as in the Cooke aggregate we have a relatively high proportion of deleterious material in addition to the typical Uhthoff types, which, while displaying the same mode of cracking at first rapidly deteriorates and "pops out". The source of this material is readily traceable to the quarry face and specifically to the lower 3 to 4 ft. and a thin band 0.3 to 0.5 ft. in thickness in the middle of the face. Cooke was and is quarrying 3 and possibly 4 ft. below the lower level of satisfactory rock. If we eliminate this from our examination of the surface the extent of cracking appears to fall more in line with the Uhthoff situation.

The general consensus of opinion regarding surface treatment jobs with Cooke's aggregate appears to be favourable, at least in terms of their performance thus far. Our examination confirms this opinion. There is very little cracking of the particles and the actual loss insofar as we can judge visually runs up to a maximum of approximately 20 percent, much of which can be accounted for by the breakdown of deleterious particles. We have not as yet had the opportunity to examine any concrete pavements but the cracking is apparently absent from a variety of structural concrete jobs at different locations. Exposure of the material to the elements in old stockpiles, locations of continual wetting and drying, old stone walls, etc., etc., does not appear to produce the same cracking leading us to the inevitable conclusion that it is the result of the hot-mix paving procedure. Perhaps the incipient weakness is already there and only accentuated by the process, we do not however have any evidence to support this at the present time.

If hot mixing is the reason then we would expect the condition to show itself fairly rapidly. We do have a certain amount of evidence to support this line of thinking but as yet not conclusively. We have observed cracked particles in the freshly rolled H.L.6 surface, Cont. 71-211 on Highway 7 east of Woodbine Avenue and in the portion of Cooke's job surfaced this year. Since there has been very little breakdown of the deleterious material the cracking is not readily apparent in this section of the Midland job.

The most obvious possibility is the heat cycle. Limestones do lose strength up to the temperature at which they are calcined, however, although we are not certain of the temperatures actually achieved by individual particles, it seems probable that it is considerably below this. Limestones of a type similar to the Uhthoff stone can lose up to 50 percent of their original strength at temperatures around 500°F but the literature is not too specific as to whether or not the strength is regained upon cooling. If heat were the cause we would expect the particles to be shattered or at least the failures would be irregular tension cracks. Our observation indicates that while a few particles are shattered the majority are only split into several pieces, often only two or three, by cracks which appear to be relatively smooth-sided shear failures. This being true, it would point either to some other destructive agent or to something in addition to the temperature factor.

Again the obvious choice is the steel-wheeled roller, a feature of the hot-mixed hot-laid paving procedure. At first glance the bearing pressure of the roller (estimated at 250 lbs. per lineal inch) would seem to be far below the compressive strength of even the weakest limestone, but perhaps in combination with the heating and possibly other factors which we have not so far discovered it may be sufficient to do the trick.

The percentage of flat particles, from a strength point of view, might at first seem to be an attractive possibility but the cracking appears to affect all particles alike, and furthermore some of the quarries in the Milton-Hamilton area with the flattest aggregates in the Province produce pavements with the least cracking. We have subjected the aggregate to tests in the laboratory to simulate severe cyclic freezing and thawing, and, heating and cooling to represent severe diurnal temperature change - to all of which the aggregate remains impervious. Of course, if climatic conditions were the reason then the aggregate would break down in all uses not just hot-mix work.

In summary, we have two phenomena present in the hot-mix pavement aggregate from Cooke's quarry; firstly a type of cracking characteristic of the geological horizon to which this quarry and also the Uhthoff quarry belong, and, secondly, the breakdown and eventual disintegration of impure material of a different type.

We have not and are not at present considering the first phenomenon to be deleterious. The second phenomenon definitely is deleterious and we should not consider re-establishing the quarry for hot-mix paving use until they have eliminated this material from their product.

In terms of the cause and effect of the "non deleterious" cracking, priority seems to lie with the effect which may relate to the pavement in ways other than loss of aggregate.

Rock cores are being prepared for compression testing, possibly through a range of temperatures, to evaluate the strength characteristics of several varieties of the limestone. If strength appears to be the major factor we may start looking at the L.A. loss to compare the degradation with other limestone control samples. We shall have to expand our thin section analysis to cover the cores and possibly aggregate specimens before and after passing through the asphalt dryer to determine at what stage the weakness reveals itself.

In the field it would be desirable to evaluate the heating against the rolling possibly with a test section using the rubber-tired roller alone and with samples of the asphalt mat before and after rolling.

To add insult to injury, this relatively narrow band of rocks that we know are the Black River formation having been accused and found guilty of alkali-carbonate reactivity and polishing like glass now suffers the final degradation of not even being able to keep its integrity.

K. W. Ingham,
Geologist.

KWI:mv

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Cook Quarry [illegible]